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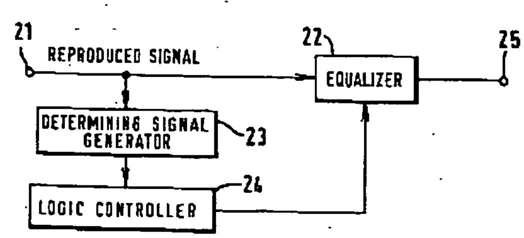
(54) **Signal equalizer.**

(57) A signal equalizer (21-25) for equalizing a waveform of a digital data sequence includes a discriminator (23) for discriminating average measurement levels at plural frequencies of the digital data sequence, an error operating unit (35) for finding the ratio or difference between an equalizing target average level which correspond to the plural frequencies that has been found in advance and an average level obtained by the discriminator and a controller (24) for controlling an equalizing characteristic of the equalizer based on the error information obtained by the error operating unit.

FIG. 2A



EP 0 622 798 A2

The present invention relates to a signal equalizer which performs a waveform equalization for a digital data sequence reproduced from a digital data record medium, such as, an optical disc and a magnetic disc.

A known apparatus for automatically equalizing waveforms of signals reproduced from record medium, for example optical discs, has been constructed, as shown in Figure 1. generally, in such record medium a specified data pattern sequence, a so-called reference signal or a training signal, is recorded on a predetermined position thereof for use in the automatic waveform equalization.

Referring now to Figure 1, a reference signal is searched for by a reference signal searcher 11. The reference signal searched for by the reference signal search section 11 is extracted by a reference signal extractor 12, and then applied to an equalizer 13. The equalizer 13 performs a waveform equalization for the extracted reference signal and feeds the equalized signal to an output terminal 14. The equalized signal output from the equalizer 13 is also input to a determining signal generator 15. the determining signal generator 15 generates error information by comparing the waveform or frequency spectrum of the equalized signal from the equalizer 13 with a target characteristic signal of the so-called reference signal or training signal. This error information is input to a logic controller 16. The logic controller 16 controls the equalizing characteristic of the equalizer 13 so as to make the waveform or frequency spectrum characteristic of the equalizer 13 close to the target characteristic signal based on the error information. 5 The logic controller 16 also controls reproducing apparatus for the search of the reference signal.

As described above, the known waveform equalization system corrects the waveform equalization characteristic based on error information by trial reproduction of a predetermined reference signal and then determining whether there is an error, i.e. a difference from the target characteristic, or not.

The known waveform equalization system is time inefficient, because it needs extra time for reproducing the recorded signal and then for searching for reference signals from the reproduced signals. Further, once having determined a waveform equalization characteristic, the characteristic is maintained until the reproduction of one disc terminates. It would be better to modify the waveform equalization characteristic according to the recording positions on the disc. However, this known system could not respond to such a demand. To respond to this demand, suitable reference signals must be recorded at different positions (e.g. at an outer recording area, an intermediate recording area, and an inner recording area of a disc), and the waveform equalization characteristic must be established for each recording area of the disc. As the reference signal is a type of finite length integrated signal, this known system has the problem that if disturbances occur because of defects of the record medium, it becomes difficult to preserve normal operation. Further, the conventional system has the problem that certain areas must be reserved on the record medium for recording the reference signal, thus resulting in a reduction of the amount of information recordable on the record medium.

The present invention seeks to provide a signal equalizer which is able to establish a waveform equalization characteristic which is effective in time utilisation.

The present invention also seeks to provide a signal equalizer which is able to determine a waveform equalization characteristic during a normal signal reproducing operation.

Still further the present invention seeks to provide a signal equalizer which is able to endure some disturbances, i.e. defects, in the record medium.

Further the present invention seeks to provide a signal equalizer which is able to carry out an improved waveform equalization over a whole record area to make good use of the record medium.

A signal equalizer according to one aspect of the present invention comprises a discriminator for discriminating average measurement levels at plural frequencies of a digital data sequence, an error operating unit for finding the ratio or difference between an equalizing target average level, which corresponds to the plural frequencies, that has been found in advance and an average level obtained by the discriminator and a controller for controlling an equalizing characteristic of the equalizer based on the error information obtained by the error operating unit.

The signal equalizer of the above aspect of the invention employs an average recording frequency spectrum unconditionally determinable by a data recording modulation system as a reference spectrum. Thus it does not require the recording or use of a reference signal as in the described known equalizer. So, even in a normal signal reproducing operation, the average spectrum of the output signal may be automatically equalized to come close to the target spectrum (or a supervisor spectrum) which has been established based on the reference spectrum and the reproduction limits characteristic.

For a better understanding of the present invention and many of the attendant advantages thereof, reference will now be made by way of example to the accompanying drawings, wherein:

Figure 1 is a diagram showing a waveform equalizing apparatus known to the applicant;

FIGURE 2A is a diagram showing one embodiment of a signal equalizer according to the present invention;

FIGURES 2B to 2D are diagrams showing detailed constructions of the units 22, 23 and 24 of FIGURE 2A;

FIGURE 3A is an eye pattern diagram of signal prior to equalization in the equalizer 22 of FIGURE 2A, for explaining the operation of the equalizer according to the present invention;

FIGURE 3B is a graph showing a power spectrum characteristic of signal prior to equalization, for explaining the operation of the equalizer according to the present invention;

FIGURE 4 is a diagram showing exemplary tap coefficients, for explaining the operation of the equalizer according to the present invention;

FIGURE 5A is an eye pattern diagram of signal after equalization in the equalizer 22 in FIGURE 2A, for explaining the operation of the equalizer according to the present invention;

FIGURE 5B is a graph showing a power spectrum characteristic after the equalization, for explaining the operation of the equalizer according to the present invention;

FIGURE 6A is a block diagram showing another embodiment of a signal equalizer according to the present invention: and

FIGURE 6B shows a detailed construction of the determining signal generator 54 of FIGURE 6A.

The present invention will be described in detail with reference to the FIGURES 2A through 6B.

Referring now to FIGURES 2A to 2D, a first embodiment of a signal equalizer according to the present invention will be described in detail. In FIGURE 2A, an input terminal 21 receives a reproduced signal (or a digital data sequence) reproduced from record medium (not shown) such as an optical disc. This reproduced signal is applied to an equalizer 22 and a determining signal generator 23. The equalizer 22 equalizes the waveform of the input reproduced signal, and feeds the equalized signal to an output terminal 25.

The equalizer 22 is constructed as shown in FIGURE 2B. In FIGURE 2B, the signal on an input terminal 22a is delayed by a period of one sample (i.e., a time period of τ) in passing through each of n delay units T0 through Tn-1 connected in series, wherein n is an even number. Further n+1 multiplier coefficient registers K0 through Kn are connected to the input terminals and output terminals of the delay units T0 through Tn-1, respectively. The outputs of the coefficient registers K0 through Kn are sequentially added with the input signal 22a by adders A0 through An-1 and then the output of the adder An-1 is fed to the output terminal 22b. Here, if the coefficients of coefficient registers K0 through kn are controlled by control signals for equalization. the waveform equalization characteristic will be adjusted. The control signals for equalization are provided from a logic controller 24 which will be described later.

The determining signal generator 23 is constructed as shown in FIGURE 2C. In FIGURE 2C the reproduced signal on the input terminal 21 of FIGURE 2A is supplied to a sampling unit 32 via an input terminal 31 of the generator 23. The sampling unit 32 samples the input reproduced signal every time period (τ) of the delay line tap coefficients, and supplies the sampled signal to a fast Fourier transform (FFT) unit 33. Thus a power spectrum of the sampled signal is obtained as a result of the FFT operation of the unit 33. This power spectrum information is input to a power averaging unit 34. The information of each frequency is averaged for preset times of executior so as to result in an average power spectrum B. Further a determining signal generator 23 has a target table unit 36. Particular data of the power spectrum for the recording data sequence power spectrum have been previously generated and recorded as a target spectrum AP in reference to a reproduction limit characteristic.

The average power spectrum B and the target spectrum AP corresponding to the average power spectrum B are input to a divider 35. Thus data C which represents a ratio between the average power spectrum B on every frequency and the target power spectrum AP is generated from the divider 35 and fed to an output terminal 37. The logic controller 24 receives the output data C through the output terminal 37. The logic controller 24 includes an inverse fast Fourier transform (IFFT) unit 41, as shown in FIGURE 2D, which performs an IFFT operation on the data C. The result of the IFFT operation is then output as prescribed tap coefficients for the equalizer 22.

According to the above construction the tap coefficients for the equalizer 22 are controlled so that the average power spectrum B and the target power spectrum AP have a predetermined relation therebetween.

FIGURE 3A shows an eye pattern of pre-equalization data sequence, while FIGURE 3B shows a characteristic diagram of the average power spectrum B obtained by sampling the data sequence at a sampling frequency fch, and then carrying out the fast Fourier transform operation at 2048 points of the frequency spectrum.

The target power spectrum AP corresponding to the average power spectrum B is stored in the target table unit 36. FIGURE 4 shows the tap coefficients obtained for the equalizer 22, by calculating the data C which represents the ratio of the target power spectrum AP and corresponding average power spectrum B, and by performing the inverse fast Fourier transform operation for the data C.

FIGURE 5A shows the eye pattern of the data sequence after a waveform equalization by 15 (n = 14) tap coefficients. FIGURE 5B shows a characteristic diagram of an average power spectrum obtained by sampling the data sequence by sampling frequency fch, and then carrying out the fast Fourier transform operation at 2048 points of the frequency spectrum. This power spectrum was confirmed to be almost

equal to the target power spectrum (i.e.. the supervisor power spectrum) AP.

The present invention is not limited to the embodiment as mentioned above. For instance, the number of points for the FFT operation or the IFFT operation can be reduced lower than 2048 points, without causing significant problems. FIGURE 6A shows a block diagram of a signal equalizer according to a second embodiment of the present invention. FIGURE 6B shows a detailed construction of the determining signal generator 54 of FIGURE 6A.

In FIGURE 6A an input terminal 51 receives a reproduced signal. This reproduced signal is applied to an equalizer 52, and wherein the waveform of the input reproduced signal is equalized.

The equalized signal is not only fed to an output terminal 53, but also applied to a determining signal generator 54. The equalizer 52, constructed similar to the equalizer 22 of the first embodiment, is supplied with a control signal for equalization from a logic controller 55.

The determining signal generator 54 is constructed as shown in FIGURE 6B. The determining signal generator 54 having the construction shown in FIGURE 6B generates totally (N-1) pieces of signals which are comprised of the input signal, and multiplied signals of the input signal with the sinewave signals or square wave signals of N pieces of frequencies (where $N \geqq 2$). The determining signal generator 54 then supplies the (N-1) pieces of signals to a common narrow bandwidth low pass filter (LPF) 65 by changing the signals sequentially. Then the output of the LPF 65 is supplied to and detected by a comparator 66 for obtaining the spectrum data B at the DC component and around the N pieces of frequencies.

When showing an example of $N = 2$, the output of the equalizer 52 is introduced to an input terminal 61 of the generator 54 as illustrated in detail in FIGURE 6B. The input equalized signal on the input terminal 61 is fed to terminals a, c of a switch 64 after being multiplied with sinewave signals or square wave signals of different frequencies, respectively, at multipliers 62, 63. While another terminal b of the switch 64 is directly applied with the input equalized signal. In the multiplier 62 the input equalized signal is multiplied with a frequency f1, while in the multiplier 63 a frequency f2 is multiplied withthe input equalized signal. A certain signal selected by the switch 64 is smoothed in the LPF 65 and then applied to a comparator 66 as a measured power spectrum B after being smoothed by the LPF 65.

This system is further provided with a target table unit 67. This target table unit 67 stores data of the target spectrum AP which corresponds to each signal on the input terminals a, b, c of the switch 64, and supplies the spectrum data to the comparator 66. The target spectrum AP is defined by adding a reproduction limits characteristic on a power spectrum of a recorded data sequence intrinsic to the recording modulation system the same as the above embodiment.

The comparator 66 outputs an error signal C between the target spectrum AP and a measured spectrum B which corresponds to the target spectrum AP, and supplies the error signal C to the logic controller 55. Then the logic controller 55 controls the tap coefficient of the equalizer 52 based on the error signal C. According to this operation the error signal C can be gradually converged to zero. As a repetition algorithm in this step, a least square algorithm which is conventionally used for an automatic equalization may be employed.

The second embodiment as mentioned above can produce the same effect as the first embodiment. Though the first and second embodiments have been explained as apparatus in which the target table units 36, 67 are originally included and predetermined, it may be beneficial to have flexibility by making the contents of the table changeable from the outside. This allows for different target characteristic depending on the recorded contents of the reproduced signal. as circumstances require.

According to this modification, if a new recording system of an optical disc or of a magnetic disc is developed, this equalization system can be applied to the new recording system. Also, it can be adapted to correspond to reproduced signals from a disc in which the characteristics of the recording data itself has deteriorated.

Further, when the table memory has sufficient capacity it may change read-out modes by making various characteristics simplified.

According to the present invention as described above, it is not necessary to record a reference signal as a record medium, differently from the known waveform equalization systems. Also, it is not necessary to search for recorded reference signals.

Furthermore, time is not needed to reproduce recorded signals for extracting the reference signal therefrom. Also, the present invention will be efficient in time utilisation because a waveform equalization system may be in motion automatically during reproduction. Also a waveform equalization characteristic can obtain the most suitable waveform in compliance with a recording position on a disc by being controlled automatically to the best characteristic anytime until a reproducing operation for one disc is terminated. Additionally it can use a record medium area effectively and can contribute to an increase in recorded density of information since recording of a reference signal is not required. Also controlled operation of waveform equalization can be obtained everytime so that, even if there are disturbances due to crosstalk or defects of the record medium, usual operation can soon be taken.

As described above, the present invention can provide an extremely advantageous signal equalizer.

That is, the present invention can establish a waveform equalization characteristic which is time efficient by arranging a waveform equalization characteristic whilst performing normal signal reproduction. It can also tolerate disturbances, carry out good waveform equalization all over, and also can make effective use of recorded medium.

While there have been illustrated and described what are at present considered to be preferred embodiments of the present invention, it will be understood by those skilled in the art that various changes and modifications may be made, and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt a particular situation or material to the teaching of the present invention without departing from the central scope thereof. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out the present invention, but that the present invention includes all embodiments falling within the scope of the appended claims.

The foregoing description and the drawings are regarded by the applicant as including a variety of individually inventive concepts, some of which may lie partially or wholly outside the scope of some or all of the following claims. The fact that the applicant has chosen at the time of filing of the present application to restrict the claimed scope of protection in accordance with the following claims is not to be taken as a disclaimer of alternative inventive concepts that are included in the contents of the application and could be defined by claims differing in scope from the following claims, which different claims may be adopted subsequently during prosecution, for example, for the purposes of a divisional application.

Claims

1. A signal equalizer for equalizing a waveform of a digital data sequence, characterised in that the equalizer comprises:

   means (32-34;62-65) for determining average measurement levels at plural frequencies of the digital data sequence;

   error operating means (35,36;66,67) for finding the ratio or difference between an equalizing target average level, which corresponds to the plural frequencies, that has been found in advance and an average level obtained by the determining means; and

   controller means (24,55) for controlling an equalizing characteristic of the equalizer based on the error information obtained by the error operating means.

2. A signal equalizer a waveform of a digital data sequence, characterised in that the equalizer comprises:

   input means (51) for receiving the digital data sequence;

   means (32-34) for discriminating average measurement levels at plural frequencies of the digital data sequence from the input means;

   error operating means (35,36) for finding the ratio or difference between an equalizing target average level, which corresponds to the plural frequencies, that has been found in advance and an average level obtained by the discriminating means; and

   controller means (24) for controlling an equalizing characteristic of the equalizer based on the error information obtained by the error operating means.

3. A signal equalizer for equalizing a waveform of a digital data sequence, characterised in that the equalizer comprises:

   output means (53) for outputting the digital data sequence:

   means (62-65) for discriminating average measurement levels at plural frequencies of the digital data sequence from the output means;

   error operating means (66,67) for finding the ratio or difference between an equalizing target average level, which correspond, to the plural frequencies, that has been found in advance and an average level obtained by the discriminating means; and

   controller means (55) for controlling an equalizing characteristic of the equalizer based on the error information obtained by the error operating means.

4. A signal equalizer as claimed in any preceding claim, wherein the digital data sequence is a normal reproduced signal which does not have a specified training signal for controlling the equalizing characteristic.

5. A signal equalizer as claimed in any preceding claim, wherein the equalizing target average level is a table in which data has been preset.

6. A signal equalizer as claimed in claim 5 preceding claim, wherein the present data of the table are changeable with different data from outside.

7. A signal equalizer according to claim 1 or 2 or any of claims 4 to 6 appended to claim 1 or 2, wherein the determining means (23) includes a fast Fourier Transfer unit (33) for analysing a sample of said digital data sequence to obtain a power spectrum, thereof and means (34) for averaging

the power spectrum at a plurality of frequencies corresponding to the plural frequencies of the equalizing target level.

8. A signal equalizer according to claim 3 or any of claims 4 to 6 appended to claim 3 wherein the determining means (54) includes means (61 to 63) for multiplying the digital data sequence sequentially with a plurality of frequencies, a narrow band low pass filter (65) and means (64) for feeding the separately multiplied signals sequentially through said low pass filter (65) to produce a power spectrum averaged at a plurality of frequencies corresponding to the plural frequencies of the equalizing target level.

FIG.1

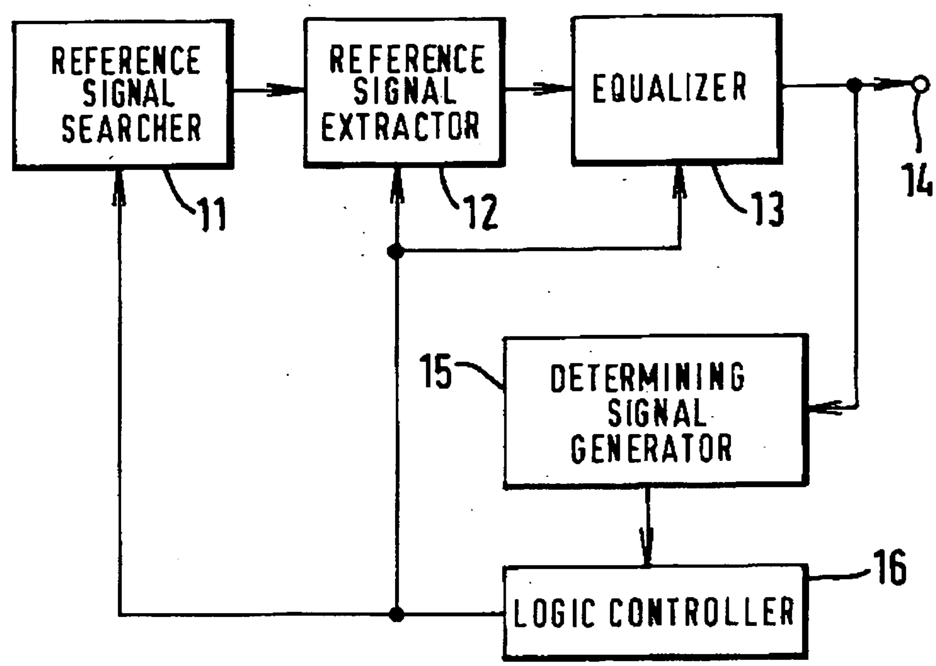

REFERENCE SIGNAL SEARCHER
REFERENCE SIGNAL EXTRACTOR
EQUALIZER
11
12
13
14
15
DETERMINING SIGNAL GENERATOR
LOGIC CONTROLLER
16

FIG.2A

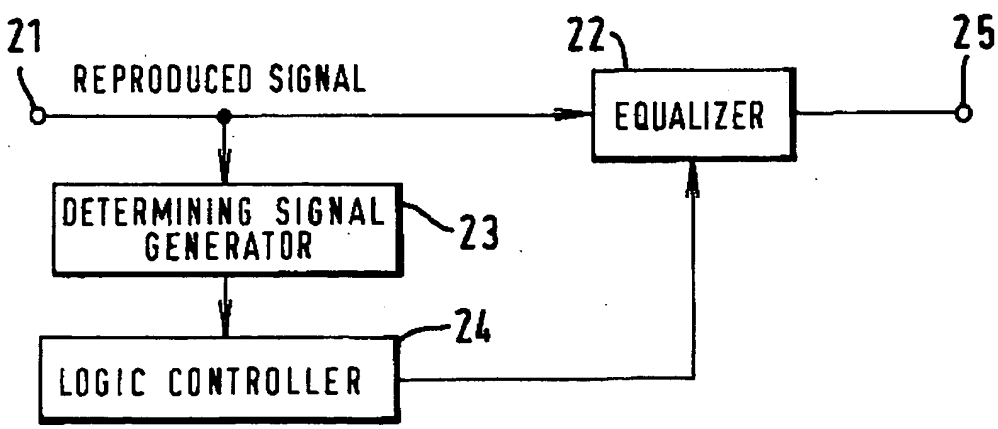
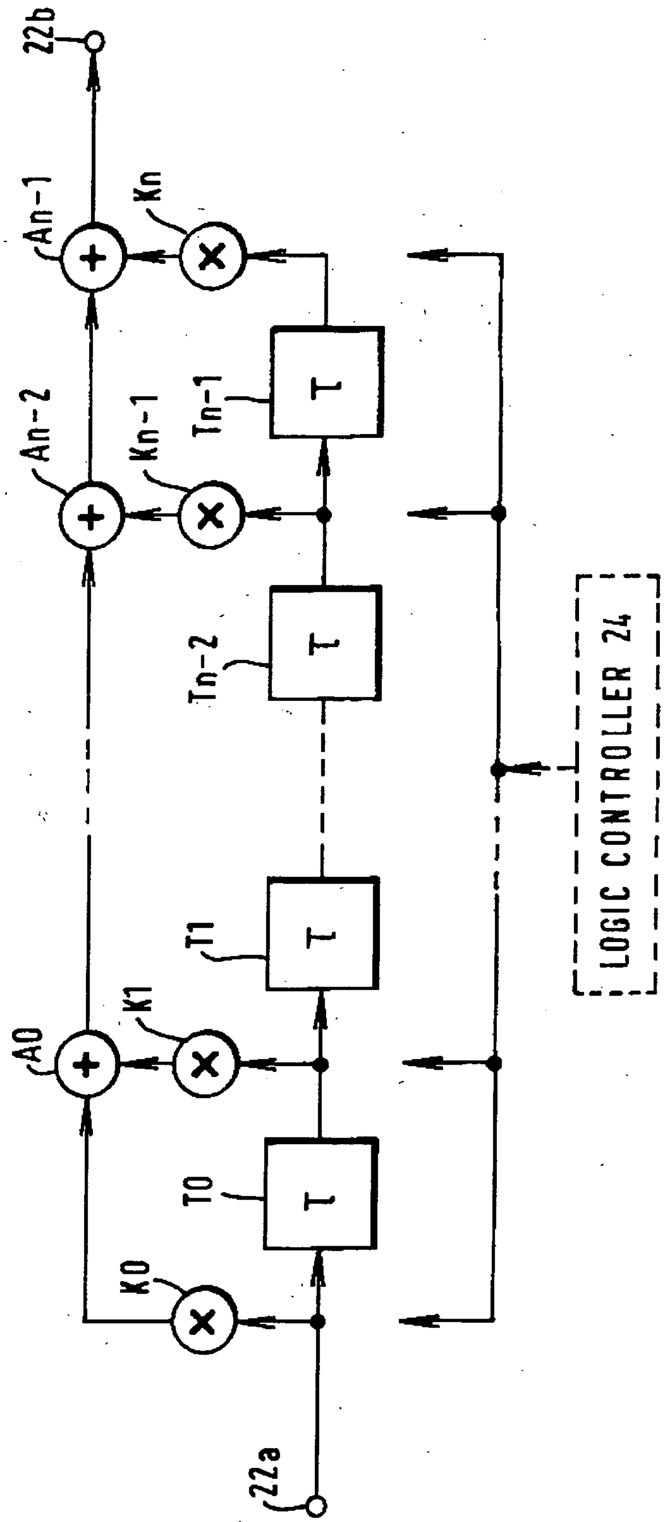

21
REPRODUCED SIGNAL
22
EQUALIZER
25
DETERMINING SIGNAL GENERATOR
23
24
LOGIC CONTROLLER

FIG. 2B
EQUALIZER 22



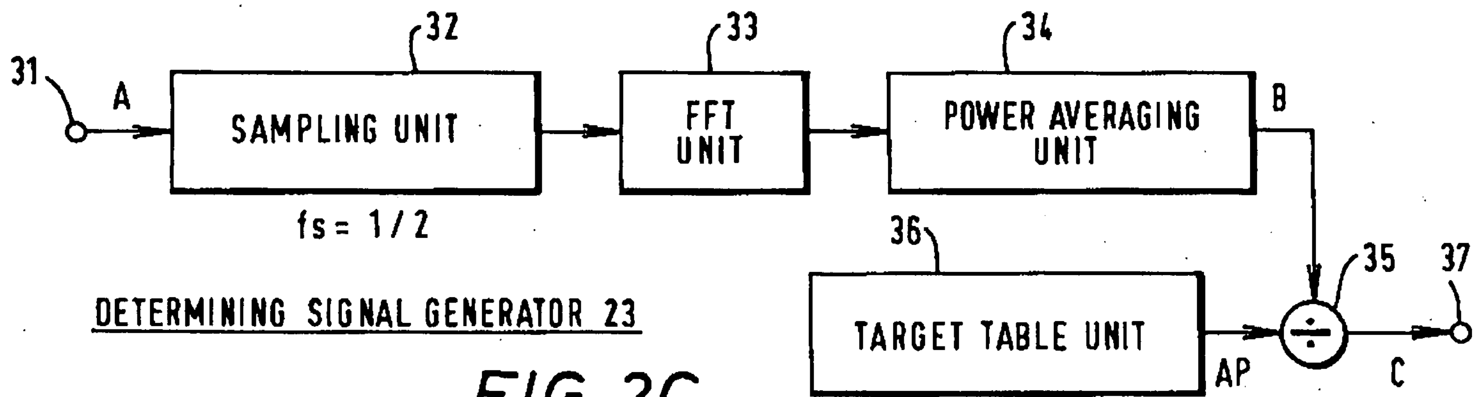

31
A
32
SAMPLING UNIT
fs = 1/2
33
FFT UNIT
34
POWER AVERAGING UNIT
B
36
TARGET TABLE UNIT
AP
35
37
C
DETERMINING SIGNAL GENERATOR 23

FIG. 2C

FIG. 2D

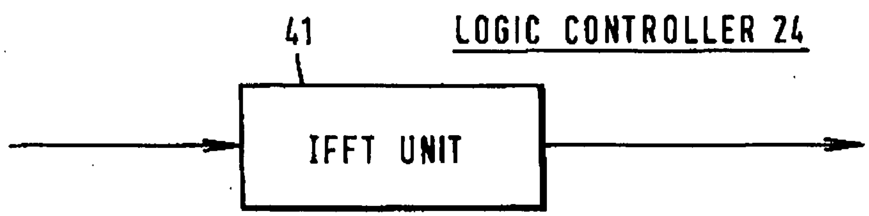
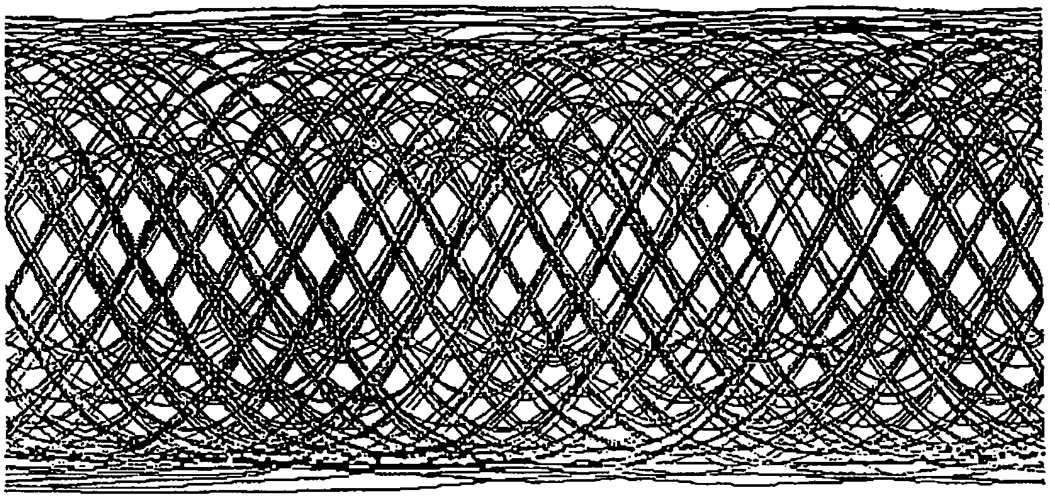
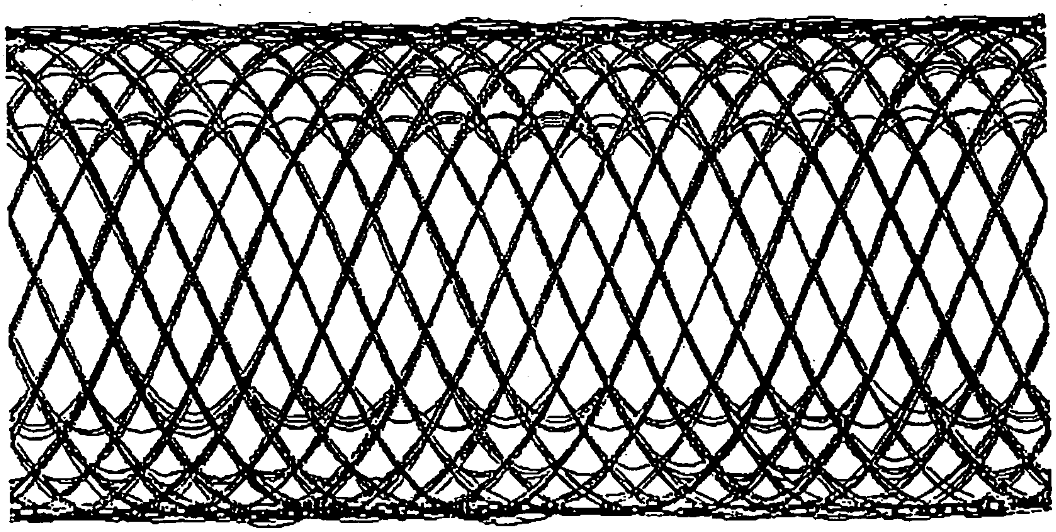

41
IFFT UNIT
LOGIC CONTROLLER 24

FIG. 3A



EYE PATTERN OF PRE-EQUALIZATION DATA SEQUENCE

FIG. 5A



EYE PATTERN AFTER EQUALIZATION OF DATA SEQUENCE

FIG. 3B

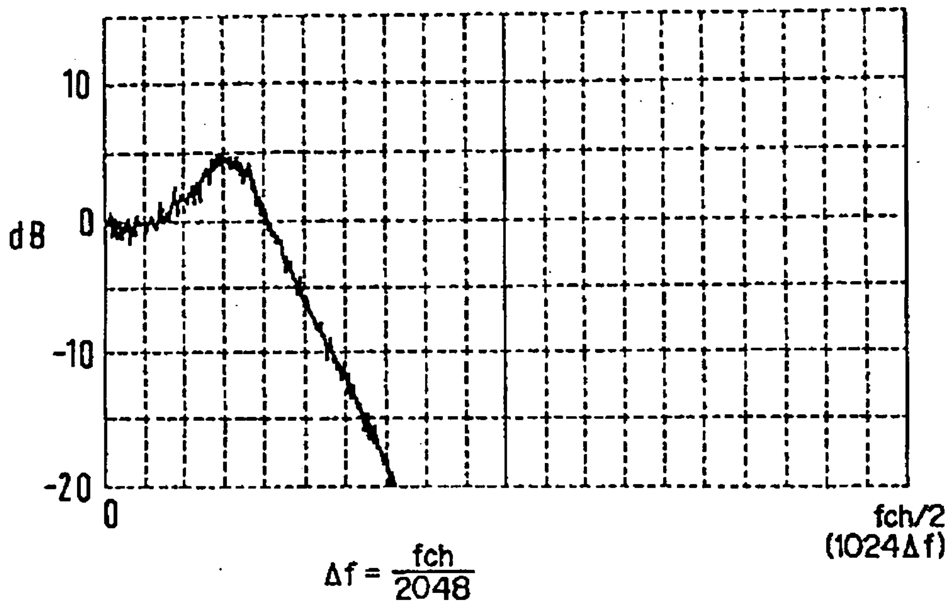

10
dB
0
-10
-20
0
fch/2
(1024Δf)
Δf = fch/2048

FIG. 5B

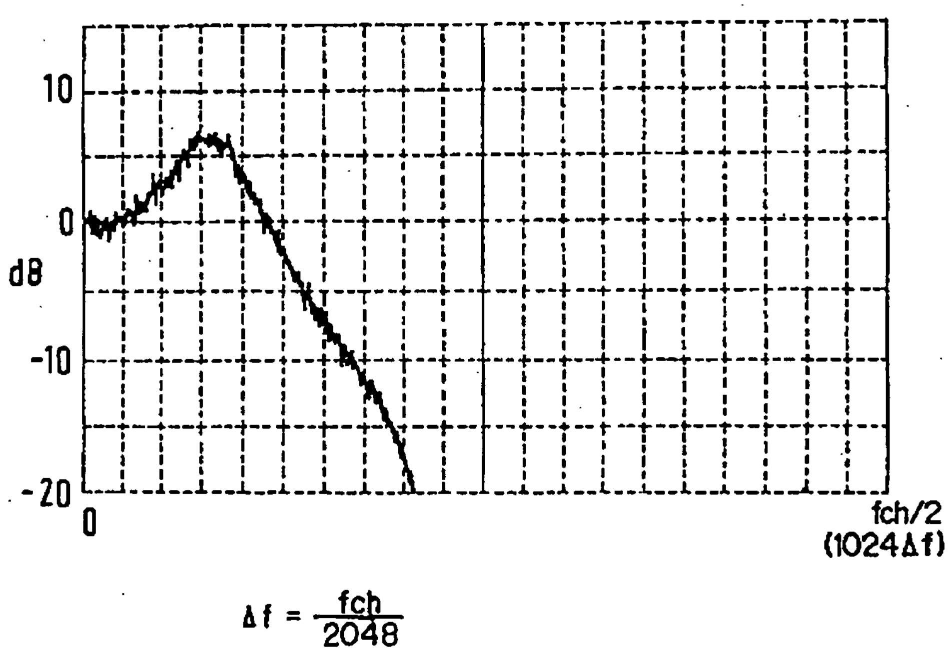
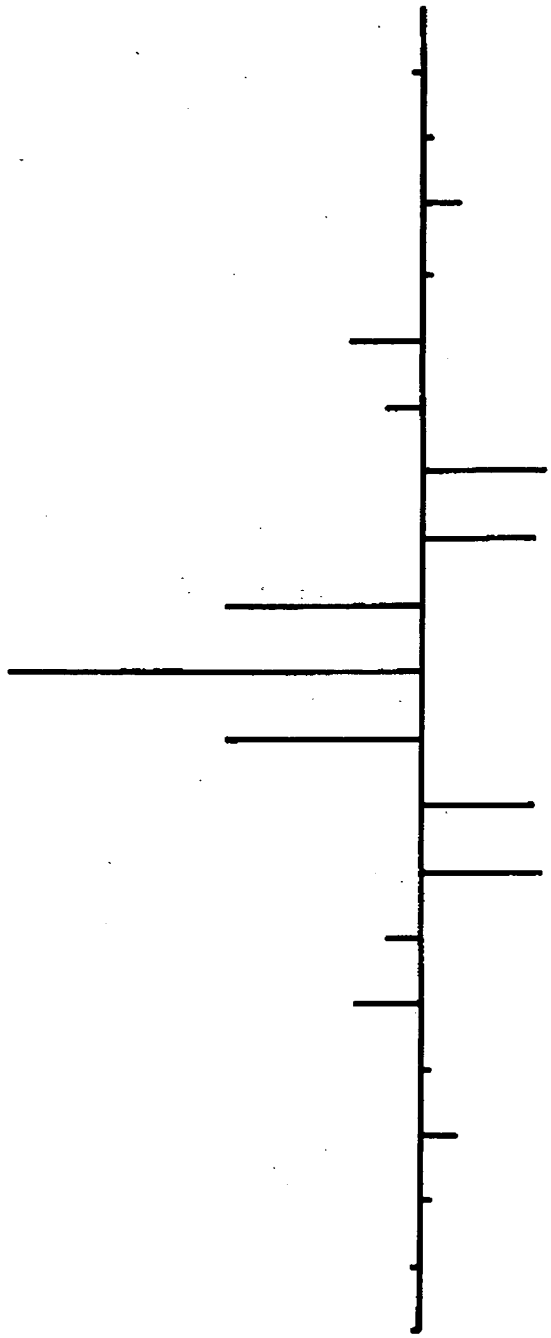

10
0
dB
-10
-20
0
fch/2
(1024Δf)
Δf = fch/2048

FIG. 4



TAP COEFFICIENTS FOR EQUALIZER 22

(TAP INTERVAL ; $T = \frac{1}{fch}$)

FIG. 6A

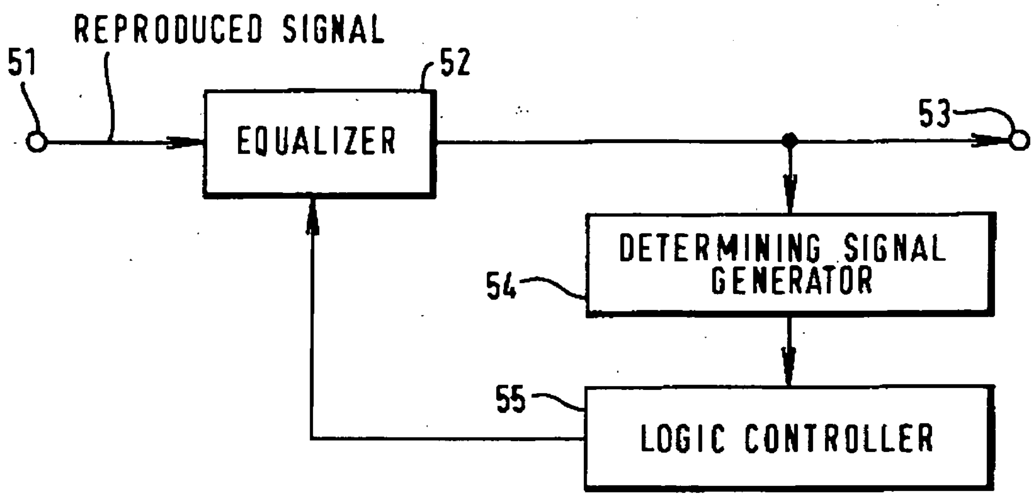
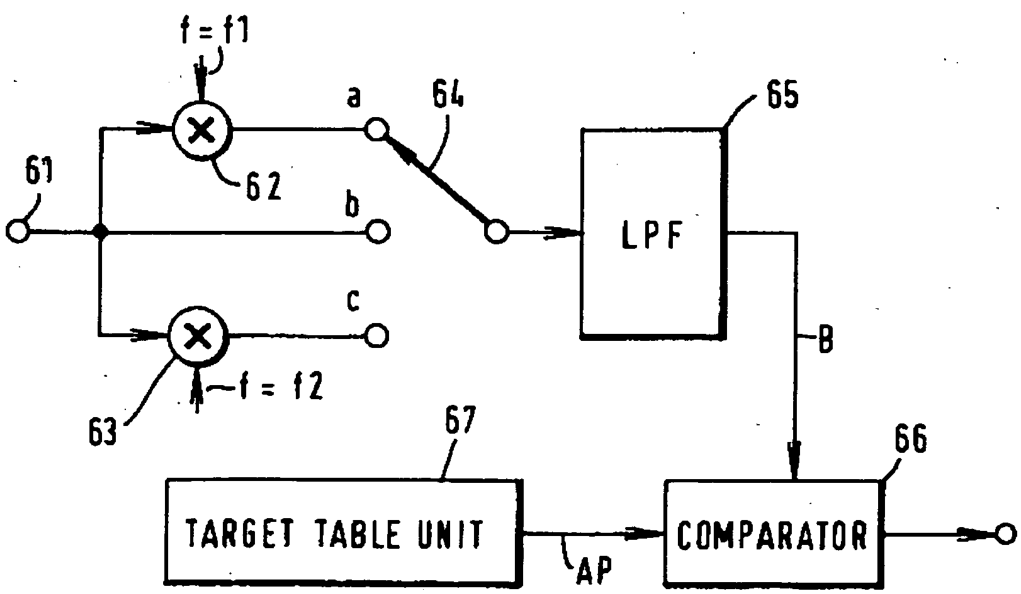

REPRODUCED SIGNAL
51
52
EQUALIZER
53
DETERMINING SIGNAL GENERATOR
54
55
LOGIC CONTROLLER

FIG. 6B


f = f1
a
64
65
61
62
b
LPF
c
B
f = f2
63
67
66
TARGET TABLE UNIT
COMPARATOR
AP